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CHEMICAL INHOMOGENEITY OF WELD JOINTS  
OF ALUMINUM-BERYLLIUM ALLOY

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Wright-Patterson Air Force Base, Ohio

19 November 1974

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By: M. A. Komarov, A. V. Lobzhanidze

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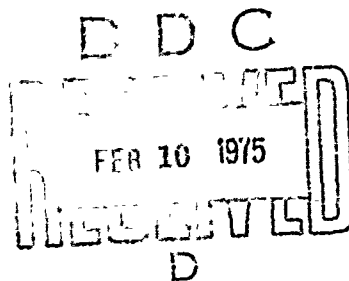
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# U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Я я	<i>Я я</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

\* ye initially, after vowels, and after ъ, ѣ; e elsewhere.  
When written as ѣ in Russian, transliterate as yě or ѣ.  
The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH  
DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	$\operatorname{sech}^{-1}$
arc csch	$\operatorname{csch}^{-1}$
<hr/>	
rot	curl
lg	log

## CHEMICAL INHOMOGENEITY OF WELD JOINTS OF ALUMINUM-BERYLLIUM ALLOY

The formation of inhomogeneity of distribution of beryllium over the cross section of weld joints of an aluminum-beryllium alloy was studied. This inhomogeneity is explained by a redistribution of beryllium due to a variable solubility at the solid-liquid interface.

Recently, information has appeared on aluminum-beryllium-base alloys combining high values of strength and elastic modulus with a low specific gravity. Some studies [1, 2] indicate a satisfactory weldability of alloys of this group, but no data are given on special studies of welding.

The authors tested argon arc welding of an aluminum-beryllium alloy, performed with a nonconsumable tungsten electrode at a constant direct current in a chamber with a controlled atmosphere. Butt welds made in this manner on material 2.00 mm thick had a qualitatively shaped seam without pores, cracks or other defects.

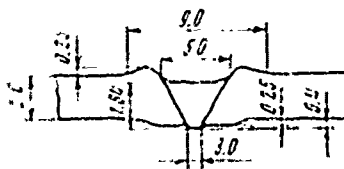


Fig. 1. Configuration of a weld joint of an aluminum-beryllium alloy.

A visual inspection and study of the macrostructure revealed the specific configuration of a weld joint, characterized by an enlargement of the cross section in the heat-affected zone and a reduction of the cast metal of the seam (Fig. 1).

A metallographic inspection revealed certain structural characteristics in the heat-affected zone. As is evident from Fig. 2, the base metal shows the presence of a two-phase structure consisting of particles of the beryllium component distributed with comparative uniformity through the matrix. As one approaches the seam, the amount of the beryllium component increases. Results of quantitative phase analysis made by Glagolev's method [3] over the weld joint cross section are given in Fig. 3. It is evident from the graph that the volume fraction of the beryllium component increases from 45% in the base metal to 65% in the heat-affected zone at a distance of 0.2 mm from the fusion line.

The transition zone directly adjacent to the seam is a homogeneous band (Fig. 2). A study made on the "Kameka" ionic microanalyzer established that this zone consists of practically pure beryllium.

Thus, as a result of the action of the heat cycle during welding of the aluminum-beryllium alloy, a redistribution of beryllium in the heat-affected zone takes place, leading to enrichment with beryllium of portions of the metal heated to high temperatures. In particular, the beryllium content of certain parts of the weld joint is 1.5 times as high as in the base metal.

The phenomenon observed may be due only to intensive diffusion processes. In the general form, the diffusion equation is written by using the concept of the chemical potential of the diffusing element, which is a function of the concentration (c), elastic deformation ( $\epsilon$ ) and temperature (T) [4].

$$\frac{dq}{dt} = D \frac{dc}{dx} + D_r \frac{d\epsilon}{dx} - D_r \frac{dT}{dx} \quad (1)$$

In this case, when the content of the beryllium component at different points of the base metal is practically the same at the start of the process, Eq. (1) is written in the following form:

$$\frac{dq}{dt} = D \frac{dc}{dx} + D_r \frac{dT}{dx} \quad (2)$$

since



Fig. 2. Microstructure of weld joint (X340).

Thus, the redistribution of the alloy components in the heat-affected zone will be determined by the elastic deformation gradient and temperature gradient arising during welding. Apparently, the highest value is that of the temperature gradient, since in the zone to high temperatures, elastic deformation is insignificant because of the low yield of the material, and in the zone where elastic deformation exists, the temperature is too low for the development of diffusion processes.

The temperature gradient may be the decisive factor for the occurrence of diffusion in the presence of variable solubility of a given element, so that in order to reach equilibrium, the element under consideration should shift from saturated regions to unsaturated ones. Such a probability was discussed in Ref. 5. However, on the basis of an analysis of experimental data, this study concludes that almost all elements (with the exception of hydrogen) are unable to migrate over macrodistances because of a change in their solubility at different temperatures.

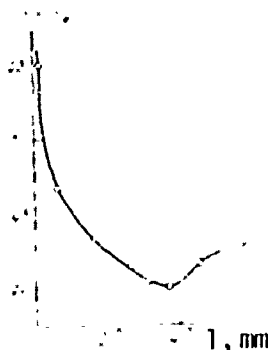


Fig. 3. Distribution of beryllium in the heat affected zone  
(l - distance from the melting zone).

In the study of weld joints of the aluminum-beryllium alloy, an appreciable difference from this conclusion was observed.

Analysis of possible reasons for this difference may be made on the basis of the Al-Be phase diagram [6].

For hypereutectic alloys, a variable solubility of beryllium in aluminum takes place at temperatures above the eutectic temperature. Moreover, the beryllium content of the liquid phase at equilibrium with the solid phase should increase with rising temperature.



Thus, because of variable solubility, a redistribution of beryllium is possible only when a liquid phase is present in the alloy, i.e., in the zone of the solid-liquid state. Experimental data and approximate calculations showed that in the welding of the alloy studied, depending on the conditions, this zone extends over 3-5 mm from the fusion line.

The following explanation may be proposed for the formation of inhomogeneity in the beryllium distribution over the cross section of weld joints of the aluminum-beryllium alloy. In the course of heating during welding, the alloy studied is in the solid-liquid state in a certain portion of the heat-affected zone. In connection with the variable solubility of beryllium, as the temperature rises above the eutectic value, the transition of beryllium from the solid to the liquid phase begins. In accordance with the concepts presented above, the presence of a temperature gradient will promote a displacement of beryllium in the direction of the heat source. The presence of the liquid component creates favorable conditions for diffusion of beryllium in substantial quantities over fairly long distances, since it is well known that the diffusion coefficients in liquid metals are several orders of magnitude as high as the corresponding coefficients in the solid phase.

It follows from the above that in the welding of alloys having a wide crystallization range, in addition to the question of redistribution of the alloy elements at the fusion boundary, it is necessary to give separate consideration to the problem of distribution of the elements along the zone length, where the alloy is in the solid-liquid state. The character of the distribution in this case will depend on the width of this zone, temperature gradient, time of residence of the metal in this state, mobility of atoms of the element under consideration in the liquid phase, and several other factors.

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